Invasive Species: An Emerging Science Application for Geospatial Information

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ABSTRACT: The spread of invasive species is one of the most daunting environmental, economic, and human-health problems facing the United States and the World today. It is one of several grand challenge environmental problems being addressed by NASA's Science Mission Directorate through national application partnerships with the US Geological Survey and the US Department of Agriculture. The invasive species problem is complex and presents many challenges. Developing an invasive species predictive capability could significantly advance the science and technology of geospatial information.

1 INTRODUCTION

Non-indigenous invasive species may pose the single most formidable threat of natural disaster of the 21st century. The direct cost to the US economy alone is estimated at $100-200 billion per year, greater than all other natural disasters combined (National Invasive Species Council, 2001). The spread of invasive species is growing as globalization increases the movements of pest and disease organisms. The issue has developed diverse stakeholder support, ranging from land management agencies, states, the agricultural industry, conservation organizations, and private landowner groups. The National Research Council's Committee on Grand Challenges in Environmental Sciences has identified increased understanding of biodiversity and ecosystem functioning as one of eight "Grand Challenges in Environmental Science" and has emphasized the need for developing improved management techniques for non-indigenous invasive species (National Research Council, 2000).

The invasive species problem provides an unusual opportunity to advance the science and technology underpinning geospatial information (Office of Science and Technology Policy, 2001). Environmental grand challenges, such as this, require problem-oriented science that can integrate physical, biological, chemical, and human systems well enough to predict the response of critical regions or phenomena to multiple causal, stressor variables. Understanding the interactions of these systems is imperative, because the many environmental factors now undergoing change make it difficult to assess the impact of any single change in the Earth system or the outcomes of mitigation strategies. This problem also is interesting in that much of the science and technology required to predict biological invasions also is required to map "hotspots" of biological diversity.

2 INVASIVE SPECIES

During the past century, non-indigenous plants, animals, and pathogens have been introduced at increasing rates into all US ecosystems. A growing number of these species are becoming invasive, and contribute to declines in native species diversity, changes in ecosystem function, and cumulative direct economic impacts currently estimated at more than $137 billion annually.

An "invasive species" is defined as a non-native species whose introduction causes or is likely to cause harm to the economy, environment, or human health. The cost of infestations of leafy spurge alone to agricultural producers and taxpayers is $144 million/year in the Dakotas, Montana, and Wyoming. Aggressive invasive fishes in the Great Lakes threaten a commercial fishery valued at $4.5 billion which supports 81,000 jobs. Invasive Norway rats cause up to $19 billion/year in environmental and economic damage. Non-native livestock diseases cost $9 billion/year. In the coming decades, increasing human travel and trade and changing types and patterns of environmental disturbance are expected to exacerbate these impacts. Because of its high diversity of environmental conditions and habitats, the US is particularly vulnerable to invasions.

The US has begun to mount an organized effort to address the invasive species threat, coalescing around Executive Order 13112 (1999). There is now a National Invasive Species Council, which has issued a draft Management Plan, and has assembled several technical working groups. The National Biological Information Infrastructure has regional programs developing invasive species information systems as their highest priority initiative, and established a national node for invasive species in 2003. Since globalization has increased the international movements of harmful species through travel and agricultural trade, US invasive species efforts are coordinated with international initiatives under the United Nations (the Global Invasives Species Programme, GISP), NAFTA (the North American Biodiversity Information Network, NABIN), the Summit of the Americas the Inter-American Biodiversity Information Network, IABIN), and a number of bilateral agreements, to develop international exchange on invasive species information.

All of these efforts recognize the central role of space-based sensors and advanced computational, modeling, and geospatial information technologies. Both the potential for movements of invasive species, and the susceptibility of sensitive habitats to new invaders are known to be strongly influenced by climate warming, changes in rainfall, soil moisture, and runoff, and are increasingly driven by extreme events. Many invasive species also greatly alter the water relations, carbon storage, fire cycle, and reflectance properties of landscapes, and may be an important feedback link to climate. Collectively, the science challenges posed by this new domain are likely to create important new opportunities for geospatial information research and development.

3 THE INVASIVE SPECIES FORECASTING SYSTEM – A CASE STUDY IN BUILDING NATIONAL CAPABILITY

High resolution mapping of biological resources is central to confronting the invasive species threat (Fig. 1). For terrestrial ecosystems, to meet the needs of the invasive species science and policy communities, we must be able to identify dominate plants and vegetation structures with a reasonable ability to distinguish between species. This is becoming possible with hyperspectral instruments at meter-scale resolutions, particularly when combined with LIDAR and other active or passive microwave sensors that can detect meter-scale vegetation structure, landforms, soil moisture, and soil surface properties. Researchers now use a variety of geostatistical, biogeographical, and remote sensing methods to map biological resources. These methods integrate multiple types and scales of data, including satellite images, aerial photography, and ground data of various resolutions. The current state-of-the-art in spatial predictive modeling, however, is still largely *ad hoc* and distributed across many laboratories and projects in universities, private-sector enterprises, and federal agencies. Many of those working in this area have come to believe that the most important next step is to pull these activities together into a coherent national capability for measuring and monitoring the spread of invasive species. This has led to the launch in 2003, of new federal invasive species science and technology partnerships.

For example, NASA's Science Mission Directorate and the US Geological Survey (USGS) now are working together to develop a National Invasive Species Forecasting System for the management and control of invasive species on all Department of Interior and adjacent lands (Schnase, *et al.* 2002a). The project will use early detection and monitoring protocols and predictive models developed at the USGS Fort Collins Science Center to process NASA and commercial data and create on-demand, regional-scale assessments of invasive species patterns and vulnerable habitats (Fig. 2). The community of ecologists and land managers who will use this application are involved in all stages of its development. The system will be made broadly available to the natural resource management community through the Internet-based USGS National Biological Information Infrastructure program.

This project will proceed through three major phases. The first phase will involve developing a prototype Invasive Species Forecasting System at selected test sites, such as Rocky Mountain National Park, CO, the Cerro Grande Wildfire Site, NM, and Grand Staircase-Escalante National Monument, UT. These sites have been chosen in consultation with the USGS ecologists, land managers in bureaus of the Departments of Agriculture and the Interior, and private stakeholder groups. At each test site, the project will compile existing field survey data, ground measurements, and airborne and satellite data. Local and regional models will be refined and tested. The second phase will expand the system to include high-resolution hyperspectral and other measurements in the modeling protocols. Doing periodic, on-demand, national assessments of management-scale risks will require unprecedented data integration and computing capacity, the infrastructure for which will be developed during this second phase. In phase three, the system will be deployed beyond the test sites and expanded into a fully operational National Invasive Species Forecasting System for use throughout the Department of Interior. The system will be made widely available to the scientific and management communities through the USGS National Biological Information Infrastructure program, which provides US interagency coordination for online biological databases and information services. (For additional information on the project, please visit our website at http://InvasiveSpecies.gsfc.nasa.gov/ .)

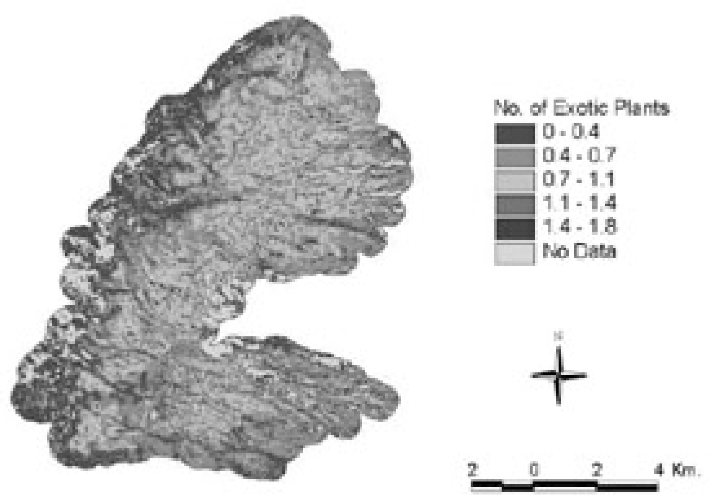

Figure 1. Predicted spatial map for the number of invasive plant species in the Cerro Grande Wildfire Site near Los Alamos, New Mexico. On-demand landscape- and regional-scale maps, such as these, that show "hot spots" for potential biological invasions, native biodiversity, and other important environmental attributes are needed for a national invasive species spatial predictive modeling and decision support infrastructure.

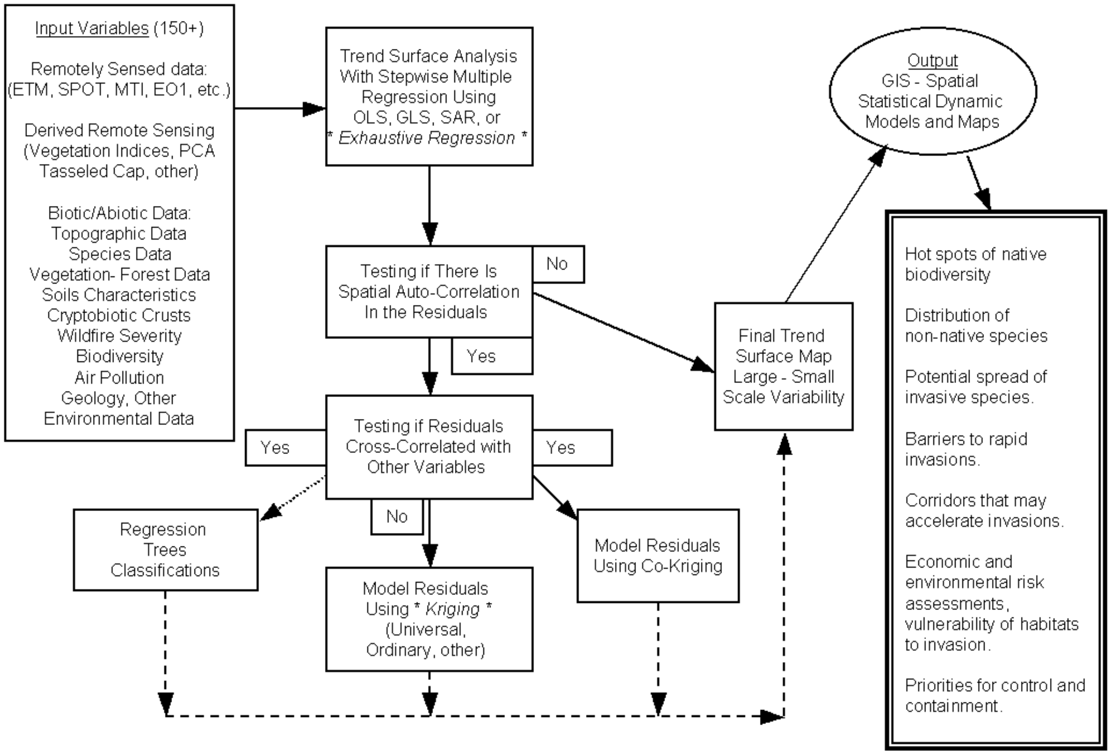

Figure 2. Steps for developing spatial statistical models. The US Geological Survey uses geostatistical methods, many derived from NASA Science Mission Directorate support, to integrate satellite, airborne, and ground data into predictive models that account for both large- and small-scale variability in landscape structure and biological resources. NASA also contributes computational capabilities and expertise in large-scale, coupled Earth-system modeling.

4 TECHNOLOGY CHALLENGES

Current ISFS methods integrate multiple types and scales of data, including satellite images, aerial photography, and ground data of various resolutions, but only on a limited bases. Most of the current work focuses on terrestrial ecosystems, but the problems extended to aquatic and marine environments as well. What we are learning here is that there is a long way to go: A robust, comprehensive, regional-scale invasive species forecasting capability of the future will require significant technology advances (Schnase *et al.* 2002b).

4.1 *New and improved measurements*

Mapping the living components of our environment and making invasive species forecasts will require innovative new interfaces between bits and atoms for an "instrumented Earth." Ultimately, we will need reliable, accurate, and timely information about ecosystem biophysical structure (biomass, vertical structure, ocean particulates, pigment florescence, trace gas fluxes, near surface atmospheric carbon dynamics, stream chemistry, etc.), ecosystem functional capacity and physiological state (pigment concentrations, live biomass, biomass turnover rates, photosynthetic and respiratory capacity, etc.), and biological population mapping (species distributions, communities, functional-type mixtures, etc.) at unprecedented temporal and spatial resolutions.

Meeting these resolution requirements will involve the development of new sensors and significant changes in the architecture of space-based observing systems. Some possibilities are smaller sensors in low earth orbit, arrayed in constellations (“sensorwebs”) of very small spacecraft with “sentinel” spacecraft at much higher orbits making near-continuous observations; embedded macro-/nanosensor webs with space-based coordination; adaptive spatio-temporal observations; change detection sensors with nested intensity design; and hierarchical 3D sensing for atmosphere, land, and oceans. Soon NASA hopes to have made significant progress toward the goal of “anywhere, anytime, anyscale sensing on demand.”

4.2 *Modeling requirements*

While major advances have been made over the past two decades, ecological forecasts of the type we describe here are still constrained by critical gaps in understanding, and by an inability to deal effectively with uncertainty. We need significant advances in our ability to interactively couple ecological models with other Earth system component models, including socioeconomic models; diagnose and address current gaps in underlying scientific knowledge; deal more effectively with prediction uncertainty; and foster innovative approaches.

Dealing with the invasive species problem will require a new class of hybrid predictive models — models that combine temporal, spatial, mechanistic, stochastic, and scenario-based approaches. These models also must be scalable and able to accommodate the vast range of spatio-temporal events that influence biospheric phenomena.

4.3 *Geospatial information management requirements*

Future invasive species forecasting systems will require advances in our ability to merge, analyze, interpret, and distill complex spatial information, ranging from the molecular level to the ecosystem level to the global level. This need to synthesize large, widely distributed, and disparate data sets and to support analysis, modeling, and interpretation at varying spatial and temporal scales pushes the boundaries of what is known and what is being done in computer and information science today. In many cases, wholly new approaches to geospatial and temporal data management will be required, as will advances in computer-mediated collaboration, simulation and visualization, knowledge discovery, and data mining.

Meeting these challenges will require increased collaboration among computer, ecological, and social scientists and end users, and will foster novel interdisciplinary work. Managing complexity, in all its forms, provide development challenges equal to, if not greater than, those required for satellite engineering.

5 WHY NASA? WHY NOW?

NASA’s involvement in this problem is new, and people often are curious about our participation. But it makes great sense. The National Invasive Species Council has noted, “no comprehensive national system is in place for detecting and responding to incipient invasions.” Yet the threat of invasive species is perhaps our most urgent economic and conservation challenge. There is a growing sense among land management agencies that a national assessment of native and non-indigenous plant diversity needs to be completed on all public lands. Especially high on the agenda are issues such as detecting the loss of native plant diversity caused by non-indigenous plant species, predicting where non-indigenous species are most likely to damage native diversity so that management can be targeted at the most vulnerable areas, and developing a science-based long-term monitoring plan for vegetation and soil resources.

NASA has a uniquely complementary and synergistic role to play in helping understand and manage invasive species. NASA currently provides measurements from Terra, QuickScat, Landsat 7, Jason and other missions that map key ecosystem attributes needed to predict invasive species distributions. A number of planned missions in the near- to mid-term will expand these measurements to include critical three-dimensional structure derived from SAR and LIDAR technologies. Measurements are also supported through data buys, including ocean color imagery from SeaWiFs, high resolution optical imagery from IKONOS, QuickBird, and other private sector satellites and land cover data from Landsat Data Continuity Mission (LDCM). In addition, NASA provides the computational capabilities and expertise in large-scale, coupled Earth system modeling needed to assure the successful transfer of these capabilities into operational use. Other spacefaring nations will contribute important resources to this effort as well.

6 CONCLUSION

In the coming decades, we hope to have refined the broad and abstract vision of ecological forecasting into a suite of practical applications for managing the environment. The invasive species problem provides an important starting point and unparalleled opportunities to advance the science and technology of geospaptial information. And since biological invasions are a global threat, any effective solution will draw on the talents of the world community and return global improvements.

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